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A process for the determination of the internal pressure of a vehicle tire

The invention relates to a process for the determination of internal pressure, particularly of the minimum pressure of the tire of a motor vehicle during driving operation, through an analysis of the characteristic vibration behavior of the wheel, whereby the standardized amplitude is determined from the vibration spectrum detected and the amplitude maxima of the resonance frequency are observed.

One such process is known, for example, from the patent document US 6,450,020 B1. The German patent document DE 101 57 858 A1 discloses a process for determining the air pressure of the tire from the vehicle operation at low and high speeds, which is prepared independently by various elements attached to the vehicle. This process is based on a resonance frequency extracted on the basis of a wheel speed signal issued by a speed sensor assigned to every wheel. The determination of the air pressure of the tire is, furthermore, based on a dynamic load radius derived from the wheel speed signal.

The intensity and frequency situation of the tire vibrations that arise during travel are highly dependent upon the internal pressure of the tire, which determines both the rigidity as well as the damping of the wheel. These characteristics also determine the intensity and frequency

with which the rim is stimulated to rotational vibrations. The rotational vibrations of the wheel can also be measured with an ABS rotational speed sensor, for example.

The rotational vibrations appear most clearly at the resonance frequencies that are dependent on the internal pressure.

In order to operate a motor vehicle as economically as possible, and in order to achieve a high level of consistency, the tires must be filled with a preset air pressure. The air pressure drops rapidly because of losses of diffusion and density in the tires. The leakage rates that arise are unavoidable, and typically lie within the range of a few 100 mbar per year. The air pressure of the tire must therefore be monitored regularly. The average driver, however, tends to either give the tire pressure no attention, or at least not the appropriate level of attention. For this reason, motor vehicles are increasingly equipped with tire pressure monitoring systems that continuously monitor the air pressure in the tires and issue a warning to the driver if the tire pressure drops below a preset minimum pressure.

Direct measuring systems are known in which a sensor that measures the pressure is located within the pressure space of the vehicle wheel. The measuring system reading out the internal pressure of the tire that is determined is, as a general rule, supplied with power by a battery and transmits its measuring data over a spark gap. The disadvantage of this system is, in addition to the operability, which is dependent on the service life of the battery, also the unbalanced dimension on the rim, ranging up to 20 g, that comes about from the sensor and the power supply.

Indirectly measuring systems make use of the change in the degree of the rolling of a wheel that occurs upon changes in the air pressure in the tires. The change in the extent of

rolling is determined by means of the ABS sensors that monitor all of the wheels of a vehicle simultaneously and evaluate the corresponding data. These systems have the fundamental disadvantage that a nearly identical pressure loss in all tires, such as necessarily occurs from leakage losses, can not be detected.

The Japanese patent document JP 5-133 831 discloses a device for determining the internal pressure of a vehicle tire. In this device, the resonance frequency of the tire is determined by a frequency analysis that is carried out in relation to a speed signal of the wheel, including the vibration frequency of the tire. The current pressure is determined from the resonance frequency detected. The resonance frequency used for the determination of the air pressure varies within the range of 30 - 50 Hz. This range is adequate if the vehicle is in a lower or medium speed range. If the speed of the vehicle increases, then the vibration behavior of a tire is difficult to evaluate. As the result, the spectrum of the resonance frequency drops, and thereby impairs its significance in regard to the internal tire pressure.

A device by means of which several resonance frequencies from several frequency ranges, such as a range from 30 to 50 Hz and a range from 60 to 90 Hz, for example, are determined, is described in JP 8-219 920.

The knowledge that the wheel speed signal of a wheel being driven contains a resonance frequency of a high order, which then changes very greatly upon a change in the internal pressure of the tire if the speed of the vehicle is high, forms the basis for the process in accordance with US 6,385,553. In this publication, it is described in very detailed form how the frequency spectrum and the resonance frequency that are of interest are determined by mathematical means, such as by a Fourier transformation (FFT), for example,

so that a standardized amplitude can be plotted over the frequency.

The task which forms the basis for the invention is that of specifying a process by means of which the resonance frequency, such as determined in accordance with US 6,385,553, for example, can be assessed in order to determine whether the internal tire pressure of any given wheel of the vehicle drops below a preset value, in order to give the driver a corresponding warning signal.

A first assessment process is characterized by the following steps:

a) Determination and recording of the resonance frequency of the wheel with a preset theoretical pressure;

b) Determination and storing in memory of the gradients $_{1Theoretical}$, $_{2Theoretical}$ of the frequency curve above and below the resonance;

c) Formation of the ratio $_{Theoretical}$ from the gradients $_{1Theoretical}$ and $_{2Theoretical}$;

d) Continuous determination of the resonance frequency of the wheel in the driving operation;

e) Continuous determination of the gradients $\alpha_{1Actual}$, $\alpha_{2Actual}$ of the frequency curve above and below the resonance;

f) Formation of the ratio α_{Actual} from the gradients $\alpha_{1Actual}$, $\alpha_{2Actual}$;

g) Continuous comparison of the ratios α_{Actual} and $\alpha_{Theoretical}$ with each other;

h)   Production of a signal if the divergence from $_{Actual}$ to $_{Theoretical}$ exceeds a defined value.

In the assessment of the vibration characteristics, the ratio of the slopes to the left and to the right of the maximum is determined. The frequency range preferably lies between 20 - 60 Hz and 70 - 110 Hz. The ratio of the slopes lies in the range from -0.25 to -4.

An additional process in accordance with the invention is characterized by the following steps:

a)   Determination and recording of the resonance frequency of the wheel with a preset theoretical pressure;

b)   Determining the xdB-, particularly the 3 dB cut-off frequency $f_{G1Theoretical}$, $f_{G2Theoretical}$ of the maxima;

c)   Forming and storing in memory of the difference frequency $f_{GTheoretical}$ from the higher xdB cut-off frequency $f_{G2Theoretical}$ and the lower xdB cut-off frequency $f_{G1Theoretical}$;

d)   Continuous determination of the resonance frequency of the wheel during the driving operation;

e)   Continuous determination of the xdB-, particularly the 3 dB cut-off frequencies $f_{G1Actual}$, $f_{G2Actual}$ of the maxima during the driving operation;

f)   Formation of the difference frequency $f_{GActual}$ from the higher xdB cut-off frequency $f_{G2Actual}$ and the lower xdB cut-off frequency $f_{G1Actual}$;

g)   Continuous comparison of the difference frequencies $f_{GTheoretical}$ and $f_{GActual}$ with each other;

h)   Production of a signal if the divergence from $f_{GActual}$ to $f_{GTheoretical}$ exceeds a defined value.

This process makes use of the phenomenon that the xdB cut-off frequencies of the maxima drift in the direction of higher frequencies upon rising air pressure. The current air pressure of the tire can then be determined from the dependence. This process can also be carried out for every wheel individually, whereby a correlation of the wheels with one another is not necessary.

A third assessment process in accordance with the invention is characterized by the following steps:

a)   Determination and recording of the resonance frequency of the wheel with a preset theoretical pressure;

b)   Determination and storing in memory of the maximum amplitude value $a_{Theoretical}$ at the theoretical pressure of the tire;

c)   Continuous determination of the resonance frequency of the wheel in the driving operation;

d)   Continuous determination of the maximum amplitude value a_{Actual};

e)   Continuous comparison of the maximum amplitude value $a_{Theoretical}$ and a_{Actual} with each other;

f)   Production of a signal if the divergence from a_{Actual} to $a_{Theoretical}$ exceeds a defined value.

The standardized amplitude for the determination of the air pressure is also used for this process.

A fourth process in accordance with this category is characterized by the following steps in accordance with the invention:

a) Determination and recording of the frequency spectrum of the wheel with a preset theoretical pressure and determination of the approximate position of the resonance frequency;

b) Transformation of the differential equations describing the vibration behavior of the wheel:

    - by means of Laplace- or Fourier transformation;

c) Selection of a range $f_{Theoretical}$ around the approximate position of the resonance frequency $f_{Theoretical}$;

d) Correlation of the selected range $f_{Theoretical}$ with the transformed differential equations;

e) Computation of the rotational rigidity $c_{s, Theoretical}$ and of the rotational damping $d_{s, Theoretical}$;

f) Continuous determination of the frequency spectrum of the wheel in the driving operation and determination of the approximate position of the resonance frequency f_{Actual};

g) Selection of a range f_{Actual} around the approximate position of the resonance frequency f_{Actual};

h) Correlation of the selected range f_{Actual} of the resonance frequency determined f_{Actual} with the transformed differential equations for the determination of the rotational rigidity $c_{s, Actual}$ and of the rotational damping $d_{s, Actual}$;

i) Formation of the difference of $c_{s,\text{Theoretical}}$ and $c_{s,\text{Actual}}$, and of the difference from $d_{s,\text{Theoretical}}$ and $d_{s,\text{Actual}}$ and the production of a signal, if at least one of the differences exceeds a defined value.

For the use of the four models forming the basis for the process, suitable values must be determined in advance for the inertia of the tires J_F and the rim J_R, as well as for the tire radius r, which represent the tires and rims that are typical for the specific vehicle.

As a supplement to process four, the tire pressure can, in a fifth process in accordance with the category, also be determined directly from the parameters $p(c_s, d_s)$. This is characterized by the following steps in accordance with the invention which go beyond process four:

a) Determination of the internal tire pressure $p_{\text{Theoretical}}(c_{s,\text{Theoretical}}, d_{s,\text{Theoretical}})$ in the theoretical condition in dependence on the rotational rigidity c_s and the rotational damping d_s, whereby parameters that take into account the tires that are typical for the specific vehicle are referred to in this connection;

b) Determination of the internal tire pressure $p_{\text{Actual}}(c_{s,\text{Actual}}, d_{s,\text{Actual}})$ in the actual condition in dependence on the rotational rigidity c_s and the rotational damping d_s, whereby parameters are referred to in this connection that take into account the tires that are typical for the specific vehicle;

c) Formation of the difference from $p_{\text{Theoretical}}$ and p_{Actual} and production of a signal if the difference exceeds a defined value.

Information that is generated in the tire / wheel suspension system is filtered out from the signals of the wheel rotational speed transmitter by means of these processes (4 and 5). The information that is assessed relates to the rotational vibrations of the tire. The range of 20 - 60 Hz is preferably selected from the resonance frequency.

Instead of the production of a warning signal, it is also possible, in accordance with process 5, to compute and to display the air pressure of the tire. The natural frequency of the rotary oscillation of the rim is thereby determined from the rim speed, and the air pressure inside the pneumatic tire is computed by means of the natural frequency of the rotary oscillation of the rim. It is thereby possible to dispense with sensors for the determination of the vertical movement of the wheel and to determine the air pressure inside the pneumatic tire alone by means of the rotational movement of the tire or rim, as the case may be. The natural frequency of the rotary oscillation of the rim is dependent on pressure, so that the air pressure inside the pneumatic tire can be computed through the determination of the natural frequency.

The computation of the air pressure of the tire is advantageously carried out by means of a comparison of the natural frequency determined with comparative values recorded in advance. These comparative values of the natural frequency were measured at different rim speeds or driving speeds, respectively, and stored in a memory storage unit. A curve of natural frequencies, which can be assigned to a corresponding air pressure of the tire, consequently results from the speed value. If the computed natural frequency of the rotary oscillation of the rim is not in agreement with the comparative value, then a divergence of the air pressure, which can be computed by qualitative and quantitative means, is present.

The rim speed is suitably recorded by means of an ABS sensor that is already present, so that no additional sensor has to be provided and no additional constructional expense has to be borne in order to obtain the input quantity. The computation itself is carried out in an evaluation unit, particularly in a computer.

The computation of the air pressure of the tire is advantageously carried out under consideration of the operating parameters of the tire, particularly the temperature of the tire, because this has an influence on the natural frequency of the rotary oscillation, since the rigidity and the damping of the pneumatic tire are changed by the temperature of the tire, which points, in turn, are parameters the changing of which influence the natural frequency.

In order to be able to compute the natural frequency of the rotary oscillation of the rim, a single-tire model is used which takes into consideration the tire parameter determined in advance and, in particular, the rotational rigidity and the rotational damping of the tire, as well as the inertia of the tire and of the rim, are input as fixed quantities of the tire or of the rim, as the case may be. During a change of a tire or rim, as the case may be, correspondingly changed parameters or characteristic values must be input and new comparative values must be determined. During a change of a tire or rim, as the case may be, the system must be calibrated again with new tire parameters for tires of a different dimension or design type.

In all five processes, the signal is preferably only produced if the divergence falls short of the defined value over a determined period of time, such as one minute, for example.

The gradients $1_{Theoretical}$ and $2_{Theoretical}$ below and above the resonance are, at theoretical pressure, preferably determined

externally for one specific type of tire and are stored in
memory on a memory storage medium that can be connected with
the tires.

The xdB- and, in particular, the 3dB cut-off frequencies
$f_{G1Theoretical}$, $f_{G2Theoretical}$ of the maxima are preferably determined
externally for one specific type of tire, and are stored in
memory in a memory storage medium that can be connected with
the tire.

The maximum amplitude values $a_{Theoretical}$ at theoretical pressure
are also preferably determined externally for one specific
type of tire, and are stored in memory in a memory storage
medium that can be connected with the tire.

The first correlation of the transformed differential
equations with the transformed natural frequency curve for the
determination of the internal tire pressure $p_{Theoretical}$ or the
rotational rigidity c_s, respectively, and the rotational
damping d_s, is preferably determined externally for one
specific type of tire and stored in memory in a memory storage
medium that can be connected with the tire.

The memory storage medium can be a transponder or a bar code.
The use of a memory storage medium has the advantage that the
characteristics typical of the tire can be determined by the
manufacturer of the tire and, upon a change of the wheel,
slightly modified data can easily be assigned to the vehicle.

The dimension of the tire can be recognized through the
situation of the maximum amplitude values. The knowledge that
the side wall of a tire is generally lower for large rim
diameters than for tires with small diameters can thereby be
utilized. The lower the side wall is, the higher the natural
frequency is.

A calibration dependent on the speed of the motor vehicle is preferably carried out on the moving motor vehicle with the help of an initialization device.

For the determination of the standardized amplitude, the conversion from the time range to the frequency range is preferably carried out by means of tables.

It has turned out to be advantageous that, before the described processes for the determination of the internal pressure of a vehicle tire, systematic and stochastic interferences should first of all be eliminated from the frequency spectrum in order for these interferences to not lead to erroneous findings in regard to a tire pressure loss.

Two or more of the processes in accordance with the invention described can advantageously be combined with each other. The use of one or more processes in accordance with the invention in a tire pressure monitoring system measuring directly and/or indirectly is also advantageous in regard to the increased safety or redundancy, as the case may be, that is hereby achieved.

Outside influences brought about by the load, the temperature, the humidity, the ambient air pressure, and/or the acceleration of the vehicle can be compensated for in the assessment of the frequency curve in the driving operation. Corresponding sensors must, of course, be provided for this purpose.

If corresponding sensors are provided, then the depth of the profile, the change of which from abrasion brings about a change of the resonance frequency, can also be taken into consideration in the assessment of the frequency curve in the driving operation.

The processes described above can be coupled with an indirect system for the detection of the minimum air pressure.

The following diagrams clarify the various assessment processes. These depict the following:

Figure 1: Representation of principle of the standardized amplitude (plotted logarithmically) over the frequency;

Figure 2: Representation of principle of the gradients changing with dropping air pressure;

Figure 3: Representation of the 3dB cut-off frequencies at various maxima of the amplitude;

Figure 4: Representation of principle of the increasing amplitude maximum upon dropping internal tire pressure;

Figure 5: The dependence, in principle, of the standardized amplitude on the air pressure of the tire;

Figure 6: The model for the description of the wheel vibrations;

Figure 7: The superimposed frequency curves in accordance with the model and the values from the wheel rotational speed transmitters;

Figures 8 to 10: Frequency curves.

The characteristic vibration behavior of a tire can be determined from the signals of the wheel rotational speed transmitter, such as are used in anti-blocking systems. Here, the representation in accordance with Figure 1 depicts the

dependence of the standardized amplitude plotted
logarithmically over the frequency. The determination of this
curve is explained in very detailed form in US 6,385,553, or
in DE 101 57 885, so that no additional explanations have to
be made about this.

With dropping internal tire pressure, the quantities of the
damping and rigidity of the tire that are dependent on the
pressure bring about a relative amplification of the
stimulation of the rim at frequencies below the resonance
frequency, and a reduction at frequencies above the resonance
frequency. The gradients of the amplification below and above
the resonance can be determined after the assessment of the
wheel rotational speed signals (such as by means of Fourier
transformations through integral numbers of rotations at
approximately equal speed, for example) and can be used at
theoretical internal pressure, by means of a comparison with
the theoretical condition of the tire previously calibrated,
as a dimension for a possible minimum air pressure. The
gradients $_{Actual}$ and $_{Theoretical}$ are placed in a ratio to each
other. If this value lies outside tolerance values set over a
defined period of time, then a warning of excessively low tire
pressure occurs.

A representative amplitude spectrum must be used in the
determination of the resonance frequency. Stationary driving
conditions need to be determined for this. An adequate
resolution of the frequency must also be ensured. A large
number of averagings of the values determined provide a good
estimate of the air pressure, consider the weighting of road
ratios (poor surface, level surface), and allow a
standardization of the vibration identity.

Figure 3 depicts the 3dB cut-off frequencies, which are
determined from the amplitude maximum. The difference
frequency f_G is determined from the difference of the upper

cut-off frequency f_{G2} and the lower cut-off frequency f_{G1}. Upon
dropping air pressure, the difference frequency is reduced,
since the standardized amplitude increases, which leads in
turn to a compression of the frequency curve (compare Figure
2). The smaller the difference frequency is, the lower the air
pressure is. If the difference frequency drops below a preset
value for a defined span of time, then a signal is produced
which indicates the minimum air pressure.

It can be inferred from Figure 4 that the amplitude shifts
into the direction of lower frequencies if the internal tire
pressure drops. At the same time, the maximum value of the
amplitude is increased. The maximum is determined and compared
with the theoretical value. If the maximum value currently
determined increases above a preset value, then the signal
indicating the minimum pressure is produced.

The location of the cut-off frequencies f_{G1}, f_{G2}, the quantity
of the gradients $_{Theoretical, Actual}$, and the value of the maximum
amplitudes $a_{Theoretical}$, a_{Actual} are, in addition to the air
pressure, dependent upon a multiplicity of additional
parameters, such as the type of tire and the abrasion
condition, for example. The tire pressure monitoring system
working with the proposed processes must therefore be
calibrated. A set of calibration parameters is thereby
recorded. An initialization device must be activated in order
to trigger the initialization. It is thereby reported to the
system that all of the tires have been correctly filled.
Internal calibration data sets are preferably recorded for
different speed- and wheel momentum ranges. If driving is
carried out for the first time after the activation of the
initialization by means of a speed range, then the set of
calibration parameters is always determined for this range.

Outside influences which influence the location of the values
stated above can be compensated for if suitable measured

values are available in the vehicle. These can be determined
by means of corresponding sensors. The wheel load can be
determined from the level regulating system. The temperature
can be taken into consideration through the external
temperature sensor, in connection with a temperature model for
tires, if necessary. Accelerations and decelerations of the
vehicle can be determined by means of the ABS sensors or the
brake light switch. The ambient air pressure can be taken into
consideration from the engine control unit. The depth of the
profile can be determined through the determination of the
extent of rolling (ground covered / wheel rotational speed).

Figure 6 depicts the model for the determination of the tire
vibrations. The wheel consists of the rim 1 with the inertia J_F
and the belt 2 with the inertia J_R. The wheel is connected, by
way of the wheel suspension, with the suspension 4, and the
damping unit 5 with the construction 3. The damping of the
rotational vibrations of the wheel is carried out, by way of
the rotational spring / absorber unit 6, with the spring
constants c_s and the absorber constants d_s. The construction
spring 4 has the spring constants c_a, and the construction
absorber 5 has the absorber constants d_a. The belt 1 is moved
with angular velocity, and the rim 1 is moved with angular
velocity. The wheel receives the stimulation for vibration
from the road with the force F_t.

If only the wheel alone is considered, and if the connection
of the wheel to the construction 3 by way of the suspension 4
and the damping unit 5 is disregarded, then the rotation of
the tires 1 and the rim 2 can be described, in accordance with
this model, by means of the following differential equations:

The rotational rigidity c_s and the rotational damping d_s are
dependent, among other points, on both the air pressure p and
the type of wheel suspension, as well as the driving speed.

The dynamic rolling radius r is, in this formulation, replaced by a constant tire radius R.

The differential equation system stated above can be advantageously and rapidly solved with a Laplace transformation in the frequency range. First of all, the differential equation system is rewritten into a first-order system:

Once rewritten, this yields the following differential equation system:

This differential equation system is now subjected to a Laplace transformation. In this, the following is valid:

- with the complex variable s.

As the result of that, a linear equation system is obtained from the differential equation system:
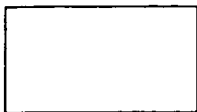
A   * =

Let:

A =

If the following is now assumed:

$$\boxed{S = i\,\omega}$$

($i^2 = -1$, ω= cyclical frequency);

and if it is considered that:

[ ]

-- then the frequency response is obtained directly, without having to state F_t:

[ ]

By means of the tire model, it is possible to determine the natural frequency quickly and accurately, without tedious measurements. The ABS signal provides the frequency spectrum of the rotary oscillation of the rim, as it was measured. One example of a frequency spectrum 10 measured is depicted in Figure 8a. A second frequency spectrum 20 in accordance with Figure 8b is obtained by applying a Dirac impulse or a tangential stimulation F_t, to the model, in accordance with which the frequency spectrum 20 of the model is computed in dependence on the model parameters.

Through the variation of the parameters in regard to the rotational rigidity c_s and the rotational damping d_s, the model can be calibrated to the measured spectrum for a specific speed and a specific air pressure of the tire, such as, for example, by determining the minimum of the total of the squares between the model and the spectrum measured, which is depicted in Figure 9.

The tire is identified by means of the set parameters c_s for die rotational rigidity of the tire and d_s for the rotational damping of the tire, and the tire model can be used in order to determine the actual air pressure of the tire. This is brought about through the fact that the frequency spectrum measured is adjusted to the model frequency spectrum through variations of the air pressure inside the model. An adjusted

frequency curve is depicted in Figure 10. As soon as a
sufficiently accurate agreement is achieved between the
measured frequency spectrum 10 and the model frequency
spectrum 20, the air pressure of the tire that is actually
present is determined and can be reported by way of a display.
In an alternative manner, a warning can be issued in the event
of a falling short or an exceeding of the boundary value.

In an alternate manner to the explicit solution of the
differential equation system above by means of Laplace
transformation, empirical solution functions that contain the
adjustable parameter can be used. For example, a typical
spectrum can be described for the specific vehicle by means of
the following model equation for the amplitude:

- whereby the constants a, b, e, and n must be adjusted to the
vehicle, and n must lie between 0.3 and 0.9. The result of
this determination can be seen in Figure 7.

The solid line represents the standardized amplitude spectrum
of the wheel rotational speed transmitter, while the dotted
line represents the result of the model. The air pressure of
the tire p is determined from the values for rigidity and
damping c_s, d_s that have been determined, through adjustment of
the model curves computed on the measured curves as function p
= f (c_s, d_s).

The elimination of systematic and stochastic interferences in
the frequency spectrum in the foreground of the processes
described for the determination of the internal pressure of a
vehicle tire has proven to be useful in order for these
interferences to not lead to erroneous findings in regard to a
loss of tire pressure.

The following types of systematic interferences must be eliminated from the spectrum:

1. Interferences accumulating synchronously with the rotary motion of the wheel, such as the pole pitch error of the encoder for the measurement of the wheel speed, general tire and rim irregularities or even mounting tolerances, for example.

2. Interferences due to vibrations in the drive branch which only appear on the driven wheels.

3. Interferences due to mono-frequent stimulations of the road.

For the elimination of these interferences, the noise frequency is first of all identified and the amplitude corresponding to this frequency is then replaced in the spectrum by the average of the amplitudes of the adjacent frequencies, for example. It is thereby recommended to also eliminate higher orders of these noise frequencies. Upon an integral multiple of the engine base frequency, as well as, at times, upon an integral multiple of half the engine base frequency, noise frequencies of the engine, for example, have been shown to be dependent on the construction type of the engine.

The following processes are used for the identification of the different systematic noise frequencies:

On (1): Noise frequencies are the wheel rotational frequency and its integral multiple in the relevant frequency range.

On (2): -- Noise frequency is the engine rotational frequency, computed from the engine rotational speed of the vehicle data bus, such as the CAN, for example, as well as the integral multiple

of the engine rotational frequency and half the
engine rotational frequency. If the information
on the engine type, for example, is located on
the vehicle data bus, or if this can not be
derived from the information present there,
then it is recommended to only eliminate the
orders that are relevant for the specific
engine type.

- Gear rotational frequencies, computed from the
wheel rotational speed (if applicable: also the
engine rotational speed) and the transmission
ratios / numbers of teeth.

On (3): Noise frequencies that are stimulated by the road
can be detected on the front- and rear wheel of the
same vehicle side. These can be identified through a
comparison of the spectra of the front- and rear
wheel for signals determined at the same time.

The result of this process step is an unfiltered frequency
spectrum that is cleaned up in regard to the systematic
interferences, such as in the form of the spectral power
density, for example.

It should be noted that it is, in essence, considerably easier
to eliminate these systematic interferences in the frequency
range than in the time range.

For the elimination of stochastic interferences, the spectra
are averaged over a longer period of time or a filtered
frequency spectrum is computed, as the case may be. Specific
quality requirements are hereby placed on an individual
unfiltered spectrum, such as the minimum energy content (since
natural vibrations are hardly expressed on very smooth roads),
distinctiveness of the peak, etc, for example.

For the event that these requirements are not fulfilled, this spectrum is not used for the computation of the average or filtered spectrum, as the case may be.